Pathways to Decarbonization

A report to the Minister of Energy to evaluate a moratorium on new natural gas generation in Ontario and to develop a pathway to zero emissions in the electricity sector.

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Executive Summary

While Ontario benefits from one of the cleanest electricity systems in North America (which contributes only three per cent of the province's total greenhouse gas emissions), the process of eliminating all emissions from the grid is a significant and complex undertaking that will require an extensive and collaborative effort to achieve.

The Pathways to Decarbonization report explores this effort, responding to the Minister of Energy's request to evaluate a moratorium on new natural gas generating stations in Ontario and to develop an achievable pathway to decarbonization in the electricity system.

Two scenarios – Moratorium and Pathways – are presented to address the Minister's request. These scenarios are not integrated power system plans. Rather, they are analyses that identify potential opportunities and challenges to consider, particularly as demand for electricity grows and Ontario's resource mix evolves. The Independent Electricity System Operator (IESO) brings the expertise and experience of the system operator to this study, and as such, the results contribute future-looking insights that can inform policy and strategy development. They make it clear that a carefully governed and orderly approach to the energy transition will be necessary to maintain reliability and manage costs.

One key insight of this analysis is that phasing gas generation out of the system will require ingenuity and the implementation of new technologies to reorient our current system, which is grounded in the flexibility that natural gas generators provide. This is in part because Ontario's natural gas fleet is capable of providing continuous, flexible energy year round and under all weather conditions, and there is currently no like-for-like replacement. This means natural gas will be needed until reliable replacements have been identified, put into service and have demonstrated their capability.

Another key takeaway is that in an environment of rapid economic growth and electrification, where demand for electricity will increase at unprecedented rates, a significant investment in new electricity system infrastructure in a relatively short period will be essential to meeting emissions reductions targets.

Understanding these issues provides a foundation for action and contributes to the ongoing conversation about the energy transition. As such, this report will inform the work of the Ontario government's Electrification and Energy Transition Panel (EETP) and the Cost-Effective Energy Pathways Study[1].

Moratorium on Natural Gas Generation

On the question of when a moratorium on new natural gas generation facilities can begin, the IESO looked at what resources would be needed to ensure reliability mid-decade and then after 2027. Against a backdrop of growing demand and increasing pressure on supply, we assessed the potential for capacity, energy and transmission expansion without additional natural gas generation after the IESO's current long-term procurement for new supply.

This assessment showed that a moratorium would be feasible beginning in 2027. At that point, the system would not require additional emitting generation to ensure reliability, provided that other forms of non-emitting supply can be added to the system in time to keep pace with demand growth. The results of this scenario would require investments of approximately $26 billion in new infrastructure.

The Moratorium scenario also shows that once the current slate of nuclear refurbishments is completed and new non-emitting supply enters the system, emissions could begin to decrease significantly. In this scenario, 4,000 megawatts (MW) of natural gas generation is retired and emissions drop by 60 per cent. Natural gas generation would, however, be needed to continue to provide flexibility to the broader system and meet local needs in the Greater Toronto Area (GTA) – an issue that the IESO is actively evaluating further.

A Pathway to Decarbonization

In the development of a pathway to a decarbonized grid, the IESO adopted a more aggressive electrification demand forecast. The Pathways scenario illustrates a system designed to meet winter peaks that are almost three times higher than those we experience today. As a result, the system would likely require an additional 69,000 MW of non-emitting supply and 5,000 MW in demand reductions from conservation.

We therefore contemplated a decarbonized supply mix by 2050 with contributions from new nuclear, conservation, demand response, renewables and storage. The mix also includes low-carbon generation such as hydrogen and renewable natural gas – currently emerging technologies – at scale. The need for a significant increase in transmission capability was also identified.

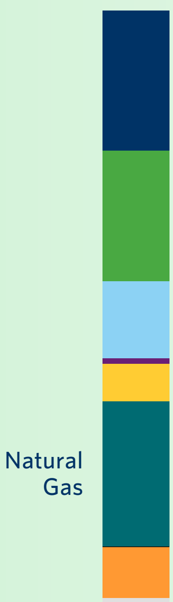
[1] To inform the work of the EETP, the Ministry of Energy is undertaking a study to understand pathways for economy-wide decarbonization. The work will begin in December 2022.

Decarbonizing Ontario's Electricity System

Bridging the work of today with the needs of a decarbonized world will be challenging and complex. Ontario's electricity system is well positioned to make the transition, but will need to address a series of challenges in order to achieve decarbonization.

System Capacity Today

42,000 MW



MANAGE COSTS

$400 billion over 2.5 decades

PREPARE FOR SITING AND LAND USE

Siting requirements **14 times** the size of Toronto

FOCUS ON INDIGENOUS PARTNERSHIPS

Increased role beyond current **20%** participation rate in electricity projects

DEVELOP CAPITAL/LABOUR RESOURCES

A potential **six-fold increase** in existing workforce to build projects

FOCUS ON INNOVATION

New technologies to drive new supply such as **15,000 MW** of hydrogen capacity

INCREASE POLICY CERTAINTY

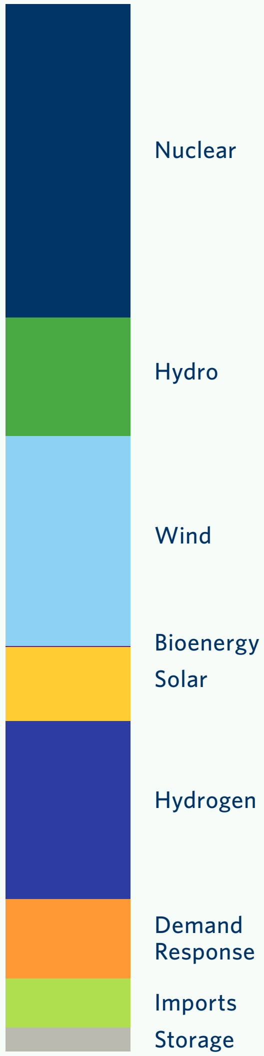
Near and long-term certainty to drive **private sector investment** in infrastructure and technology

STREAMLINE REGULATORY PROCESSES

Streamlined siting and regulatory processes keeping the **local perspective** at the core

Pathways to Decarbonization 2050 Scenario

88,000 MW



In all, the bulk system expansion needed to enable decarbonization in this scenario would require an investment in the range of $375 to $425 billion.

Both the Moratorium and Pathway scenarios demonstrate that it is possible to reliably manage the energy transition with the necessary investments, and they highlight the time, cost and risks involved. How Ontario's new supply mix actually evolves will depend on future research, analysis, consumer preferences and, ultimately, policy and investment decisions. More research and planning work will be needed to turn these scenarios into an actionable plan to move Ontario's current clean supply mix and system toward a fully decarbonized target.

Addressing Risks

Bridging the work of today with the needs of a decarbonized world will be challenging and complex. While Ontario has a very clean electricity grid today, it must still be prepared to address dependencies that are key to meeting broader decarbonization goals:

- Large infrastructure such as hydroelectric, nuclear facilities and transmission can take 10 to 15 years to build. Preliminary work should begin now so that options are available in the 2030s and beyond.
- Significant investments in capital, materials and labour will be required to build out a fully decarbonized system. One study[2] estimates that the 14,000-strong labour force currently working on electricity infrastructure projects could need to increase six-fold for decades.
- Communities and First Nations across the province have a growing voice in how and where new infrastructure is located, so meaningful and transparent discussions about siting and land use will be required.
- While many of the technologies needed to decarbonize are already known and commercialized, many others, including low-carbon fuels and small modular reactors (SMRs), are still in development. It will be important for Ontario and Canada to continue to invest in these, and other, innovations.
- Energy plans need to be approved and new infrastructure needs to be planned, permitted and sited. Regulatory and approval processes, such as environmental and impact assessments, need to be resourced appropriately and streamlined to enable this.
- Costs must be carefully managed to ensure the actual impact on total energy costs is affordable and that they do not diverge significantly from those of our neighbours. Rapidly rising electricity costs could discourage electrification, stifle economic growth or hurt consumers with low incomes.

[2] See Appendix B, section 6

Conclusions

This report demonstrates the sheer scope and magnitude of the effort needed should Ontario decide to decarbonize its electricity system while achieving a net-zero economy by 2050. The IESO has identified a number of "no regret" actions that can be taken to help meet growing demand, address retirements of existing generation and ensure a state of readiness to manage any future decarbonization policy. These actions will lay the groundwork that both builds on Ontario's already clean system and allows for progress in a shifting environment. These no regrets actions include:

- Accelerating current efforts to acquire new non-emitting supply, including the implementation of recent conservation and demand management directives.
- Beginning the planning, siting and environmental assessment work needed for new nuclear, long-duration storage and hydroelectric facilities, as well as transmission infrastructure, to allow for faster implementation.
- Investing in emerging technologies like low-carbon fuels. Further work is needed to determine if they can replace at scale some of the flexibility that natural gas currently provides the system.
- Galvanizing collaboration amongst stakeholders and Indigenous communities.
- Ensuring that regulatory, approval and permitting processes are ready to manage future investment at scale.
- Establishing an open, transparent and traceable process to measure progress and demonstrate the results of decisions and actions taken along the way.

For its part, the IESO will incorporate the many learnings from this report into its core work, including more explicitly addressing the risks of climate change and the ongoing energy transition in its planning and procurement processes.

Introduction

In Canada, as in many countries around the world, governments are developing policies aimed at achieving their own net-zero greenhouse gas (GHG) emissions economies by 2050, supported by clean electricity systems. In Ontario, the government is taking action by establishing the upcoming Cost-Effective Energy Pathways Study, as well as launching a climate change impact assessment, investing in innovative SMRs, and implementing one of the largest battery storage procurements ever undertaken. At the federal level, the government recently proposed the Clean Electricity Regulations (CER) and complementary policies to decarbonize Canada's electricity system by 2035.

At the local level, customers are also driving this transition. A movement toward environmental, social and corporate governance goals is encouraging the growth and development of non-emitting electricity resources. Businesses and homeowners are exploring how to shift away from fossil fuel-based energy for building heating, transportation, and industrial processes, among others, and they are expecting a clean electricity supply to power the transformation.

Today Ontario's electricity system is already more than 90 per cent emissions-free and the sector contributes only three per cent to the province's total greenhouse gas emissions. However, as the broader economy decarbonizes, there will be increased pressure on the grid to meet significant growth in demand for electricity.

In recognition of these trends and in response to the IESO's 2021 technical study on the phase-out of natural gas, the Minister of Energy directed the IESO to explore the feasibility of a moratorium on new gas-fired electricity generation and a pathway to a decarbonized electricity system. The Minister asked the IESO to consider reliability and cost in the analysis, and to explore low-carbon fuels and carbon capture and storage. He also asked that the report examine the role of technologies such as pumped storage and battery storage combined with non-emitting resources, as well as hydroelectric, nuclear and demand response.

In response to the Minister's request, the IESO undertook a scenario assessment exercise informed by stakeholder engagement and outreach. While not an integrated electricity system planning process, these scenarios were developed using the same tools and methodologies, and provide valuable insights into the work required to achieve this goal.

Given our mandate, this assessment focuses only on the bulk power system – i.e., high-voltage transmission lines, generation and interconnections with neighbouring jurisdictions – and does not consider the impact on local distribution systems. We expect, however, that some of the resources identified in this study will be distributed energy resources (DERs) connected within the distribution system. In developing a zero-carbon, reliable scenario and as requested by the Minister, we have used cost as a key determining factor. Our assessments, therefore result in cost-optimized supply mixes.

Consistent with many other recent studies, this report shows that achieving a net-zero economy powered by an emissions-free electricity system will involve a massive investment in new infrastructure and increased cost. It also notes that significant risks and dependencies will have to be addressed to enable implementation. It will be vital that this transition is managed prudently so that costs do not discourage electrification, negatively affect the economy, or place an undue burden on people with low incomes.

The characteristics of the scenarios presented in this report are based on current information – many other factors can, and likely will, influence what mix is ultimately put in place. These include: competition; the availability of resources, capital and labour; the impact of changing weather; the adoption rate of distribution-level resources; the level of community approval of new electricity projects; the pace of regulatory approvals; and the evolution and commercialization of certain markets and technologies, such as hydrogen, renewable natural gas and nuclear.

Climate Risk

The International Panel on Climate Change has called on nations around the world to reduce emissions by 2050 to limit temperature increases to 1.5 degrees Celsius thereby limiting the risks to natural and human systems.

Because of the accelerating effects of climate change, weather scientists forecast that Ontario's weather patterns will change significantly over the coming decades. These changes, which are well documented in the Climate Atlas of Canada, will have a major impact on how demand increases and decreases throughout the day, affecting the performance of the electricity system and the integrity of our infrastructure. If these issues are left unaddressed, there is a deepening concern that costs to the Canadian economy from weather and climate impacts will be significant, as reflected in a recent report from the Canadian Climate Institute.

It is clear that we will need to continually assess, understand, mitigate and adapt to changing weather.

Electricity System Reliability and the IESO's Role

Much of the activity of our daily lives depends on an electricity system that is reliable, meaning power is there when we need it to be. Ontario's electricity grid is one of the most reliable in the world, safely and steadily meeting the needs of the province every minute of every day. And because it works so seamlessly, its complex mechanisms are hidden – so much so that most of us only notice our electricity supply when it's not there.

In fact, our provincial grid is an extensive, dynamic and interconnected system that is both stable and nimble, with a foundation of reliable infrastructure that can respond to large and small changes whenever needed.

For the operators of this system to manage events as they occur in real time, in both normal and unexpected circumstances, many things are required: the system must meet the physical requirements of moving power along transmission and distribution lines, for example, as well as operating standards for reliability and security. It must also be able to respond to sudden changes quickly, and meet demand every hour of every day.

These responsibilities are top of mind today as a growing global momentum is driving the decarbonization of electricity systems in the pursuit of a net-zero economy. Thoughtful and detailed work has been undertaken recently in many jurisdictions, including in Canada, to explore the possibilities and timelines for moving electricity systems to non-emitting technologies.

All of these studies identify electrification as a viable option to mitigate the risk of climate change, and predict a massive build-out of electricity infrastructure. Appendix A, Tab 7 provides a high-level comparison of the IESO's results with similar studies produced by government, research institutes, regulators, and environmental organizations.

From the IESO's perspective, all of these efforts are a welcome contribution and add valuable insight to the collective understanding of what will be needed in the near and longer term. Most, however, use a relatively high-level lens, building potential supply mixes to meet only forecasted capacity and energy needs.

As the system operator and planner, we examined capacity and energy, but also factored in the requirements of the transmission system and began to consider the complexities of operating the electricity system as a whole on a day-to-day basis; this makes our contribution distinctive.

What we learned is that decarbonizing the electricity system is a complex task that must be carefully managed so as to not disrupt daily lives and the province's economy. In the modelling approach section that follows, the steps taken to develop reliable and cost-effective scenarios are described in detail.

> "Scenarios are not intended to represent a full description of the future. They highlight central elements of a possible future and draw attention to the key factors that will drive future developments. Scenarios are hypothetical constructs, not forecasts, predictions or sensitivity analysis."
>
> **Task Force on Climate-Related Financial Disclosure**

Modelling Approach

The Pathways to Decarbonization report complements the IESO's Annual Planning Outlook (APO), which accounts for demand and supply forecasts based on existing policy and project commitments, customer behaviour and available technologies. This report explores the possibilities for different patterns of consumption, broad electrification and the emergence of new technologies, as well as the expansion of the current supply mix over different time frames.

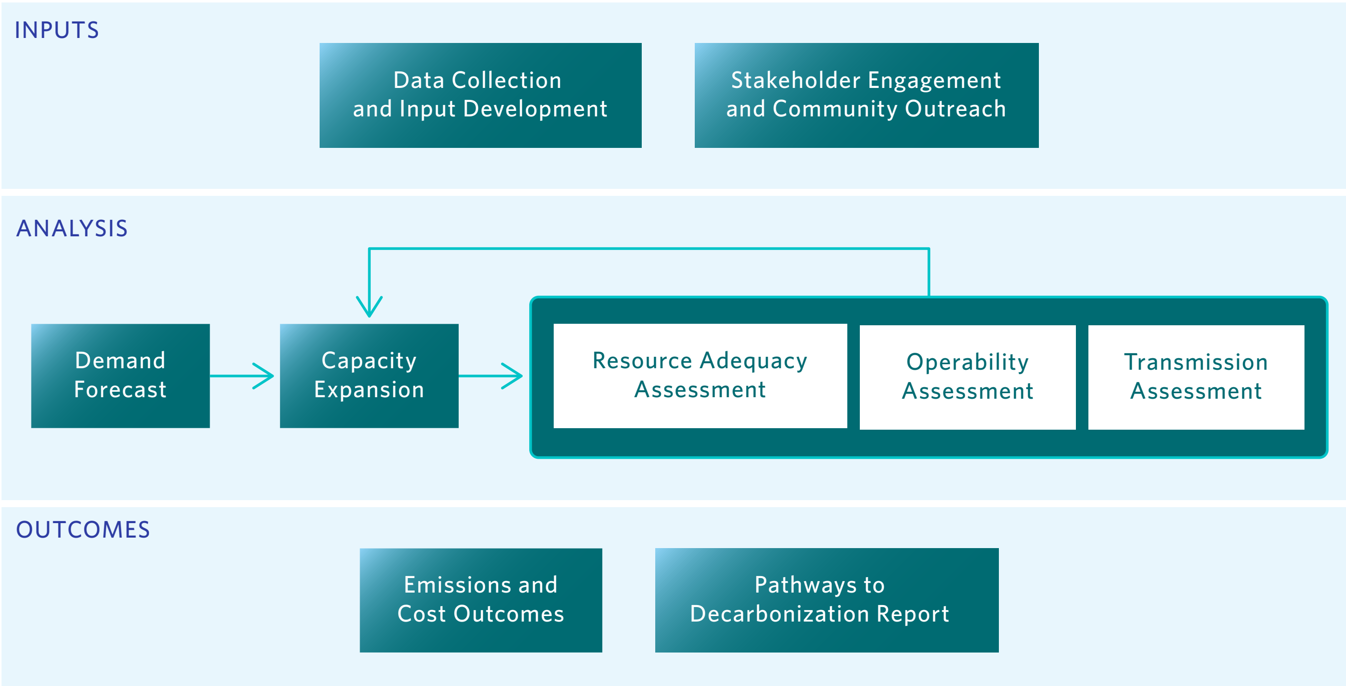
The two scenarios outlined in this report – Moratorium and Pathways – use software modelling tools, professional judgment and the set of detailed assumptions described below to simulate an energy-adequate expanded resource mix over a given time frame. The IESO created a mix based on the feasibility of new resources which accounted for build time and annual build limits, cost and performance. Only low-emissions resources that are considered technically feasible today, or that could be available within the time frame of the study, were included as potential new candidates for the future mixes.

It should be noted that reliability assessments were only performed for the final year of each scenario: 2035 for Moratorium and 2050 for Pathways. A thorough and detailed planning process would be required to identify reliable options for reaching these end-points. These plans typically take a number of years and incorporate many interdependent factors, such as facility commissioning and retirements, project planning, outages and much more.

Although this report is not a plan, it relies on the same data and expertise that the IESO uses in annual demand, resource and adequacy assessments. Technical standards that underpin the safe operation of electricity systems across the continent have been employed to highlight what a hypothetical future could look like if certain conditions were met.

The supply mix modelling and analysis process comprises a number of steps (see Figure 1), which are described in this section. The goal of this process is to develop a mix that is adequate, flexible, sustainable and diverse to ensure that the system is reliable in changing conditions.

Figure 1 | Supply mix modelling and analysis process steps



Scenario and Assumption Development

This report examines two questions: First, is a moratorium on natural gas generation possible in Ontario's electricity sector? Second, when and how can the sector be decarbonized? In response to these questions, two approaches were taken:

1. The **Moratorium** scenario, which focuses on 2035, examines whether a moratorium on the acquisition of new natural gas generation is feasible after the IESO's 2022/2023 resource procurements. (A moratorium on new gas within current resource procurements was found to be not feasible, as set out in the Resource Eligibility Interim Report.)
2. The **Pathways** scenario, which focuses on 2050, explores the time frame within which Ontario's electricity system could be **decarbonized**. In keeping with the assumptions of many other studies and to create an instructive "bookend" case to consider, this scenario assumes the decarbonization of the broader economy, which results in a significantly higher projection for demand based on substantial electrification within other sectors.

Beginning with its own information, including records for historical capacity and weather data, IESO planners compiled a list of technical assumptions for existing and emerging resources and government policy direction. They built on these assumptions using data and projections from the U.S. National Renewable Energy Lab Annual Technology Baseline – the most comprehensive and reliable information publicly available for a number of elements – as well as other sources. Policy and demand assumptions were compiled from internal research.

Stakeholders and communities also played a valuable role in shaping the assumptions used in the analysis. A formal IESO engagement with extensive outreach to sector participants was undertaken on the Pathways to Decarbonization effort between February and May to build awareness and seek input to inform the development of achievable pathways to decarbonization in Ontario's electricity sector.

Two webinars were held as part of the formal engagement initiative to provide an overview of the study approach, transparency around the modelling and analysis, and to seek technical feedback. Approximately 320 attendees participated in these sessions and more than 50 feedback submissions were received on preliminary assumptions posted for input. All meeting materials, assumptions, feedback received and IESO responses are posted on the engagement web page.

In addition, the IESO conducted extensive outreach with key communities and stakeholders to discuss this work and solicit input at a more granular level on technical assumptions, data sources, and data gaps. Over 30 meetings were held that encompassed more than 70 organizations and representatives of municipalities, generators, commercial and industrial customers, local distribution companies, environmental/sustainability organizations, Indigenous communities, sector associations, research and academia and energy consultants. This work has also been significantly informed by the expertise and advice received from the IESO's Stakeholder Advisory Committee members.

The IESO incorporated evidence-based feedback and input received in a number of areas, including in the assumptions related to policy, electricity demand, resource and technology.

The final assumptions can be found in Appendix A, Tab 1-3. A summary of key assumptions is included in Table 1. In order to be feasible, all modelling exercises involve a measure of simplification; Table 2 outlines some of these simplifications and considerations.

TABLE 1: OVERVIEW OF SCENARIO ASSUMPTIONS

Assumption Category	Moratorium	Pathways
Modelling Year	**2035**	**2050**
Carbon price (CO_2e; carbon dioxide equivalents)	$50/tonne in 2022, rising annually by $15/tonne and reaching $170/tonne by 2030.	Continues rising by $15/tonne from 2030-2035, and thereafter increases with the rate of inflation.
Emissions performance standard	As in the 2021 APO	370 tonnes (t) CO_2e/GW (gigawatt-hour) until and including 2030, dropping 74 tCO_2e/GWh per year to reach zero in 2035
Demand forecast (see Appendix A, Tab 2)	As in the 2021 APO	High-electrification forecast
Energy efficiency	Both scenarios assume the maximum level of demand reduction based on the cost-effective conservation and demand management (CDM) potential that was identified in the 2019 Achievable Potential Study	
Non-emitting resources (see Appendix A, Tab 3)	Wind[3], solar, hydroelectric, nuclear (includes large facilities and SMRs), demand response, storage, bioenergy and firm imports from clean jurisdictions	Same as Moratorium scenario, and low-carbon fuel was assumed to be available after 2035
Existing natural gas	Available for re-contracting after contract end if less than 25 years old	Before 2035, same as Moratorium. After 2035, retired at end of contract, but considered available for reliability until 25 years of age.

[3] Offshore wind was assumed to be available for development in the Pathways scenario, even though the IESO acknowledges the current moratorium on the technology.

TABLE 2: MODELLING CONSIDERATIONS

Factor	How Incorporated in the Report
Weather patterns	Historical normal weather patterns were used for this report. The IESO did not perform sensitivities to assess the impact of changing weather on normal demand.
Low-carbon hydrogen manufacture	In this report the IESO has assumed that hydrogen is produced outside of Ontario and therefore has no impact on demand. Producing hydrogen at scale within the province is expected to increase demand and the need for resources (see Enbridge's Pathways to Net-Zero Emissions In Ontario), although further work is needed to better understand the impacts of hydrogen production and deployment on the electricity system. The IESO will consider these impacts in future scenarios.
Carbon capture, utilization and storage (CCUS)	Based on feedback from stakeholders, CCUS was determined to be ill-suited to peaking applications, which is the forecasted role for the continued use of emitting supply, and was therefore not available as a resources option.
Distribution system	This study focused solely on the transmission-connected grid, and no analysis was conducted on the impact to distributions systems.
Emissions removal, including direct air capture	Emissions removal, including direct air capture, was not considered, as the Minister's request was for a zero-emissions grid.
Wind	Onshore wind was capped at 15,800 MW, limited by site quality, regulatory requirements and distance to transmission infrastructure.
Low-carbon fuels	Imported blue hydrogen combusted in a new single-cycle turbine was used as a proxy for low-carbon fuels and was assumed to be available after 2035. Low-carbon fuels include pink, green and blue hydrogen, synthetic methane, renewable natural gas and biofuels, which can all be combusted in a turbine or used in a fuel cell. (For a discussion of some of the challenges facing low-carbon fuels see Appendix A, Tab 9.)
Storage	Batteries and pumped hydroelectric storage were used as proxies for storage more generally. The IESO recognizes that other types of storage could play a role in a decarbonized future. (See Appendix B, section 4 for a description of various different types of storage.)
Firm imports	External research (see Appendix C) was performed to assess the clean-energy transitions of each of Ontario's connected neighbours, as well as their future ability to export clean energy. To guarantee the cleanliness of firm-imported electricity, firm imports were only permitted from Québec. Manitoba was not considered due to the distance to major Ontario load centres and insufficient transmission capability to enable imports.

Distributed Energy Resources (DERs)

DERs are distribution-connected facilities for local electricity generation, control and storage, and today represent at least 10,000 MW across the province. While the scenarios in this report did not distinguish between the province-wide transmission system and local distribution networks, DERs are included within the build-out of new resources.

DERs can help meet regional needs where there are existing constraints on supply, avoiding or deferring the need to build transmission infrastructure. Local electricity market pilots in York Region and Essex are exploring ways to coordinate local supply to meet local needs.

Recent research commissioned by the IESO shows that DERs have the potential to help meet Ontario's future electricity demand, and they are gaining momentum in Ontario. Infrastructure, capability and knowledge building across the province are creating a solid foundation for growth, and the IESO is working to integrate DERs into the electricity markets by 2026 to further support their expansion across the province.

Conservation and Demand Management and Mid-Term Review

The IESO's Mid-Term Review of the 2021-2024 CDM Framework includes findings and recommendations on how cost-effective CDM can best contribute to meeting evolving system and customer needs during the current framework and beyond. This includes analysis done earlier this year on how new and enhanced programs could be used to meet near-term capacity needs.

In response to these findings, the Minister issued a directive in October 2022 enhancing Ontario's CDM targets and budgets, optimizing the full potential of energy efficiency and bringing targets in line with the achievable potential estimates of the Mid-Term Review in the near-term. Current Save on Energy programs are on track to achieve all feasible energy-efficiency within the 2021-2024 framework.

Both the Mid-Term Review and this report highlight the potential for the IESO to expand the scope of its future CDM programs post-2024. They also highlight the importance of supporting efficient electrification to minimize the impacts of consumers switching from carbon-emitting fuels for space heating, transportation and other end uses. This will take focused effort, and the Mid-Term Review includes recommendations to move the sector in these directions.

Demand Forecasting

Demand forecasting is an attempt to predict future electricity demand so that the system can be effectively planned and managed, as electricity demand and supply need to be almost perfectly matched in real time. It aims to assess the causes of future changes in demand by looking at end uses and sector trends.

All sectors of the economy – residential, commercial, institutional, industrial, agricultural, transportation and others – contribute to province-wide energy demand, and the inherent uncertainty involved in predicting the future of all these elements makes forecasting demand challenging. It is clear, however, that as interest in decarbonization policies grow and economic activity increases, Ontario will see growth in electricity demand for the foreseeable future.

Capacity Expansion and Resource Adequacy Assessments

To build an adequate supply mix, the IESO undertakes a number of steps using tools, data and professional judgement. The starting point is a capacity expansion model (CapEx), which is used to assist in the design of an expanded resource mix. (More details can be found in Appendix B, section 1). This mix is run through a number of assessments to determine that it is capacity and energy adequate. At a high level, the approach is as follows:

1. Determine the least-cost supply mix based on the demand forecast, resource inputs and constraints using the CapEx tool.
2. Assess the supply mix to ensure that resource capacity adequacy is met. This determines if the least-cost supply mix satisfies Northeast Power Coordinating Council (NPCC) resource adequacy requirements.
3. Assess the supply mix in a production cost model to ensure that resource energy adequacy is met.
4. Conduct a screening of the supply mix for operability to understand the ability of the mix to manage a variety of conditions as they occur in real-time on durability, diversity and flexibility (further described below and in Appendix B, section 3).
5. Assess the supply mix to understand the ability of the system to maintain supply within established transmission planning standards (further described below and in Appendix B, section 2).
6. If the supply mix is deemed insufficient, restart the process at Step 1.
7. When a supply mix is deemed sufficient, it is then post-processed for reporting on metrics such as cost and emissions.

This approach to resource adequacy assessments is consistent with IESO system planning processes. (Further information can be found in the IESO's Annual Planning Outlook Resource Adequacy and Energy Assessment Methodology.) The resource adequacy assessment is an iterative process, along with the operability screening and transmission assessments, which are described in the next section.

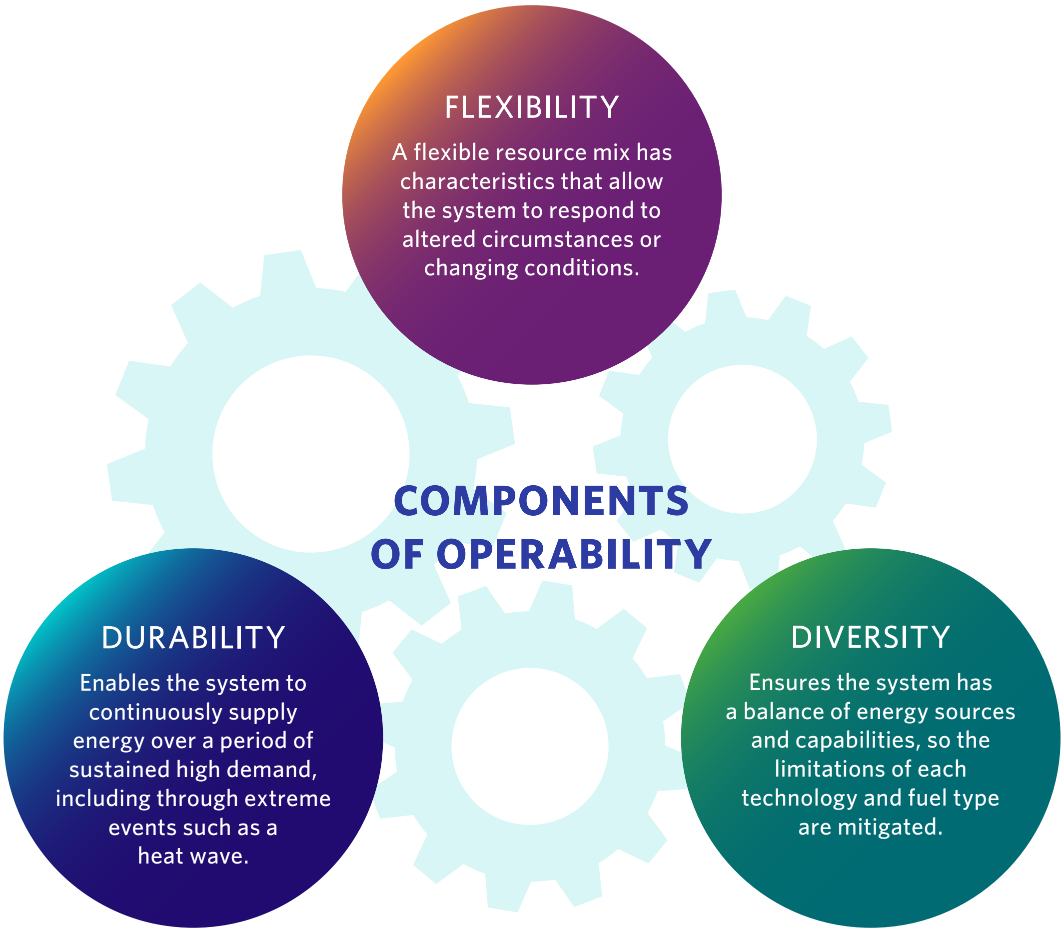
What is Capacity?

Capacity, or **installed capacity**, generally refers to the maximum output of a power station. Effective **capacity**, refers to the contribution a power station can reliably make to meet peak demand, taking into account factors such as fuel availability, ambient conditions and outages. For example, a station with an installed capacity of 150 MW could contribute only 30 per cent of that amount, and thus have an effective capacity of 45 MW.

Operability Screening

Operability refers to the ability to manage a variety of conditions on the power system as they occur in real time. It is achieved by having a resource mix that is flexible and diverse, with sufficient energy duration. By coupling resources with tools and software that improve manageability, the IESO can observe, monitor and direct the majority of resources across the system (see Figure 2).

Figure 2 | Components of Operability



For this report, the IESO conducted a limited operability screen on the resource mix for the Moratorium scenario, examining the durability, diversity and flexibility of the resource mix. For the modelled 2050 supply mix, the challenges identified in the Moratorium scenario are likely to grow, and with limited information on the operational behaviour of new technologies, the Pathways scenario could not undergo an operability screen.

The IESO plans to undertake further work in 2023 to understand the implications of increased penetration of variable resources on flexibility. A number of other future considerations were also identified that will require further study to assess the operability of the mixes. (Further information on future considerations can be found in Appendix B, section 3.)

Reliability Standards

The North American Electric Reliability Corporation (NERC) is a not-for-profit international regulatory authority whose mission is to ensure the effective and efficient reduction of risks to the reliability and security of the grid. NERC has begun to highlight the challenges of managing reliability with energy-constrained resources.

> Resource adequacy assessments have mostly focused on generation and transmission capacity available to serve peak demand. With the previous resource mix, real-time energy adequacy was assumed under that capacity umbrella and transmission was not highlighted as a requirement; however, recent extreme temperature events have shown energy adequacy to be a new dimension of risk given the changing resource mix and actual performance of the grid versus assumptions used in previous resource mix studies.
>
> **Energy Adequacy White Paper (nerc.com), December 2020**

New reliability standards are under development by NERC to address these challenges.

Transmission Analysis

The assessments in this report weighed existing and planned transmission capabilities against the two demand forecasts, evaluating the ability of the system to maintain supply within established planning standards and with the selected resource mixes. The assessments then looked at what system enhancements would likely be needed in the coming decades.

Although the capacity expansion model does not specify a location for any of the resources in the supply mixes, the options for siting certain generation types, such as pumped storage or SMRs, will be limited to a single or small number of areas. In addition, previous assessments of the feasibility of large installations of wind and solar provide guidance on the most likely locations for these types of facilities. These locational considerations informed the transmission analysis, helping to identify where new or upgraded transmission would be needed to enable the supply mix and ensure that demand can be supplied by the bulk transmission system.

If potential transmission solutions could not be implemented, (e.g., due to lead-time considerations), the assessment looked at opportunities to retain existing generation, as well as the potential to locate new supply that does not have limitations on potential siting in those areas of need.

Cost and Emissions Analysis

This report looks at costs from two perspectives: (1) cumulative capital investment in new infrastructure up to the applicable scenario study year and (2) annual system cost in the applicable scenario study year; with all costs in this report and the appendix in 2022 Canadian Dollars.

Under both scenarios, capital investment is represented as the overnight cost of "new steel in the ground" – i.e., there are no capital investments associated with resources such as demand response and conservation programs. "Overnight cost" is a common industry term, meaning the cost to build a project without consideration of financing, or the cost to complete a project if it were built "overnight".

An annual system cost includes the revenue requirements[4] for supply, transmission and distribution infrastructure; standby costs for demand response; conservation program costs; firm import agreement costs; and resource dispatch costs for a particular year.

In the Moratorium scenario, the focus is on the change in annual system costs in 2035 compared with a reference scenario with the same base supply mix, but instead of meeting reliability requirements with non-emitting resources, requirements in this reference scenario are met by extending all existing resources to the end of the study period, with incremental needs met by additional simple-cycle natural gas (a scenario approach similar to past APOs). With this comparison there is also a change in emissions and an implied cost of carbon can be calculated – i.e., the increase in annual system cost divided by the decrease in emissions.

In the Pathways scenario, the focus is on the total annual system cost in 2050, with the unit cost of demand – total annual system cost divided by total demand in the same year – calculated and compared with today's unit cost of demand. As there is no comparable emitting reference scenario for Pathways, an implied cost of carbon is not calculated.

Note that the final totals for both capital investment and annual system cost include a 25 per cent contingency. Adding a contingency is a consideration for unknown or unexpected factors, and is commonly used for a study of this nature. In addition to capturing general cost uncertainty, which varies by resource type and technology readiness, it is also meant to capture out-of-scope costs (e.g., the build-out of distribution infrastructure, which will be considerable under the Pathways scenario) and the potential for adherence to more stringent reliability criteria, requiring incremental resources.

Moratorium for the 2025-2027 Period

Addressing capacity needs arising in the 2025-2027 period, the Minister of Energy asked for an interim report, to be delivered in October 2022, that would inform immediate policy decisions for upcoming electricity sector procurements.

The IESO responded, in its Resource Eligibility Interim Report, and recommended that a diverse set of resources be included in these procurements. This included a significant investment in battery storage, balanced by natural gas capacity and other forms of non-emitting generation, to ensure reliability and affordability in the context of tight market conditions and supply chain disruptions.

The report concluded that a maximum target of 1,500 MW of new natural gas capacity will sufficiently complement other procurement streams, addressing short-term capacity needs and contributing to the province's longer-term energy transition.

[4] Revenue requirements can be contract costs or a cost of service. Both consider capital costs spread over the contract term or the life of the project, inclusive of financing, returns, taxes and accounting treatments, as well as annual fixed costs.

A Moratorium on New Gas Generation

To understand the feasibility of a moratorium on new natural gas generation, the IESO looked first at what resources would be needed to secure necessary supply for 2025-2027. The results are described in the Moratorium for the 2025-2027 Period section directly above.

It then examined the province's needs after 2027 and analyzed a scenario up to 2035 that addressed projected demand by adding only non-emitting resources to the current supply mix. The 2021 APO's planning and demand forecast was used as the basis for the scenario, as it was the most recent available data at the time the project began. As discussed below, adjustments were made to the forecast and supply mix to make the assessment more meaningful. In this scenario, the IESO only performed adequacy assessments for 2035, and therefore this report only shows capacity and energy results for that year.

Demand Forecast

The APO long-term demand forecast used in the Moratorium scenario covers the period from 2023-2042 (see Figures 3 and 4). It projects strong growth in the early to mid-2020s as a result of anticipated industrial mining projects, strong residential-sector growth and a robust commercial-sector recovery from the COVID-19 pandemic.

From the mid-2020s to the early 2030s, the forecast projects significant agricultural-sector growth and, in the early to late 2030s, expected increases in the number of electric vehicles in Ontario. (More information is available in the 2021 APO.)

Conservation and Demand Management

The APO demand forecast was updated to reflect the important role that managing demand should play in meeting future needs. Conservation, or energy efficiency, is a cost-effective non-emitting resource. Homeowners, businesses and communities can all play a larger role in saving energy and managing costs, and investments in energy-efficiency and demand management programs will be essential for maintaining reliability in the coming years.

As a result, an additional 2,200 MW[5] of demand reduction and 11.7 terawatt-hours (TWh) of energy savings, ramping up over the study time frame, was assumed along with existing efforts, together reaching a total of 3,100 MW of demand and 22 TWh of energy reduction by 2035. The amount is premised on best-in-class program delivery and incenting up to the full cost difference between baseline and efficient equipment, where it would be cost-effective from a system perspective. Successfully delivering the maximum potential savings would require increased, sustained investment in CDM programs, capability-building initiatives, and supporting marketing. It would also entail spending approximately $6.25 billion over the 2023-2035 period.

Figure 3 | Moratorium Scenario versus APO Peak Demand

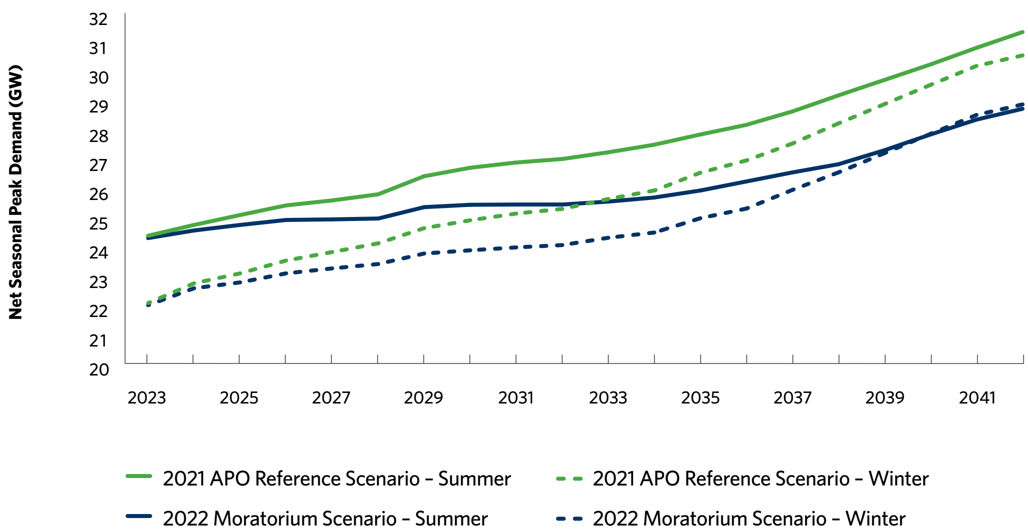
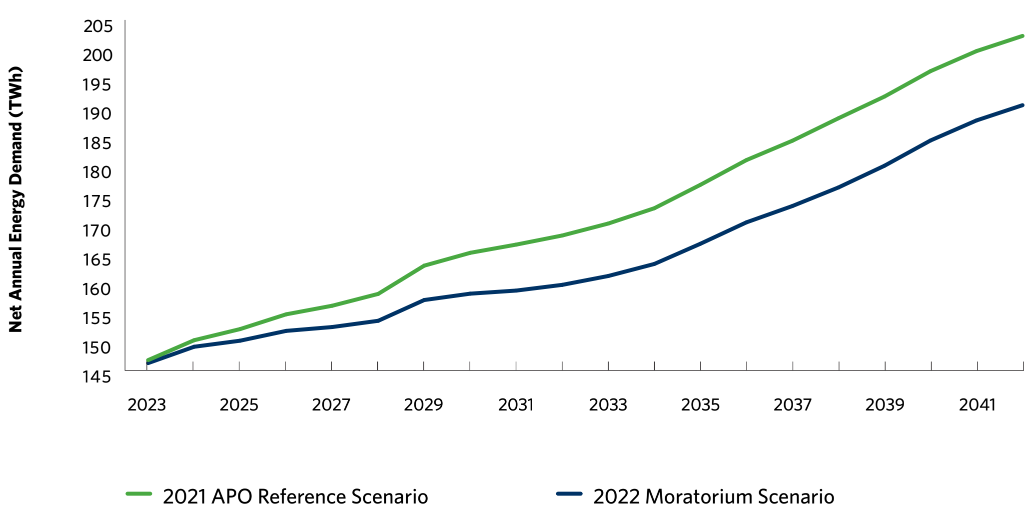


Figure 4 | Moratorium Scenario versus APO Annual Energy Demand



[5] As informed by the IESO and Ontario Energy Board's 2019 Electricity and Natural Gas Conservation and Demand Management Achievable Potential Study, Scenario B, maximum cost effective savings scenario. The IESO's Mid-Term Review undertook a 2022 refresh exercise of this study and confirmed the availability of significant cost-effective achievable CDM potential, with deeper savings over the longer term. Timing considerations did not allow for the 2022 refresh results to be incorporated in this report's modelling.

Resource Build-out

The next step in the process was to identify the base supply mix that would operate throughout the time frame of the study. The base supply mix identified in Figures 5 and 6 as "Today's Capacity Remaining in 2035" is made up of all facilities that exist in 2024 that are expected to still be in operation in 2035. It was assumed that this would include all existing non-emitting resources. Based on our assumptions, natural gas facilities began to retire over the study time frame, but were allowed to continue operating if they were needed for reliability purposes or if they were economically feasible to run. Natural gas is therefore reduced to about 8,000 MW in 2035 from the current fleet of about 10,000 MW. This reduction in gas was enabled by nuclear refurbishments, new SMRs, additional supply and significant conservation savings.

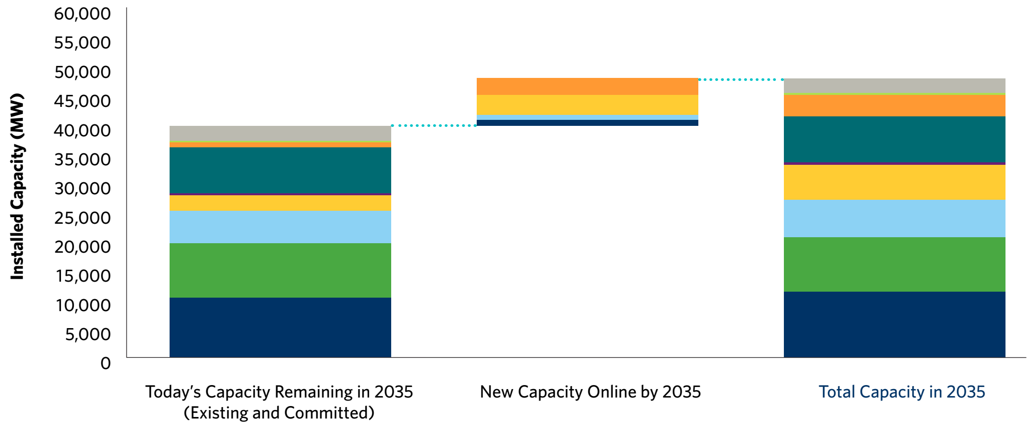
In addition, to ensure the exercise was as timely and relevant as possible, the actual or expected results from 2022 resource procurements and announced government policy were also added. These included:

- More than 700 MW of capacity from the IESO's first Medium-Term Request for Proposals, completed in June 2022;
- A 300 MW SMR, assumed to be in service in 2029; and
- 4,000 MW of supply (2,500 MW of battery storage and up to 1,500 MW of natural gas) from the Long-Term 1 procurements, assumed to be in service by 2027.

By 2035, the base supply mix had approximately 39,700 MW of installed capacity, including refurbished nuclear resources (see Figure 5, "Today's Capacity Remaining in 2035").

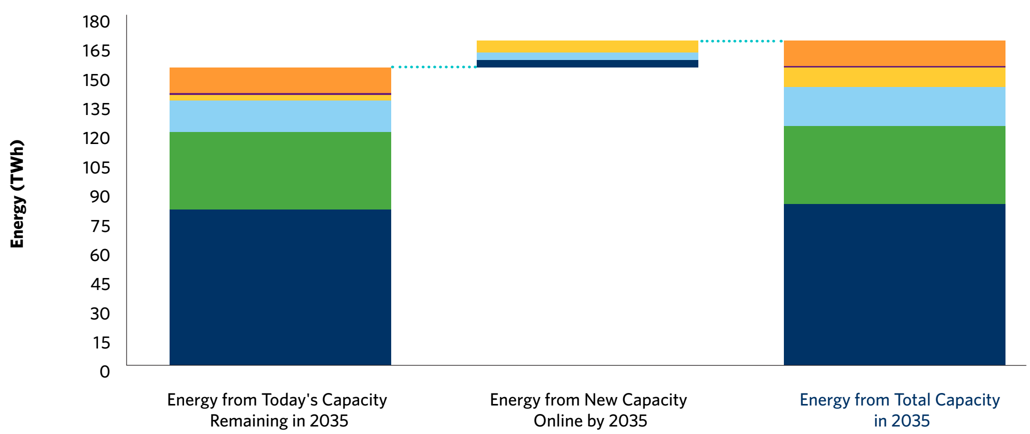
To meet projected demand in 2035, new supply was added throughout the study time frame according to need, cost, build time and other factors. Options available to "compete" included all developed non-emitting technologies except low-carbon fuels.

Figure 5 | Moratorium Scenario – Installed Capacity in 2035



	Today's Capacity Remaining in 2035 (Existing and Committed)	New Capacity Online by 2035	Total Capacity in 2035
Storage	2,507	0	2,507
Imports	331	0	331
Demand Response	808	2,885	3,693
Natural Gas	7,840	0	7,840
Bioenergy	415	0	415
Solar	2,668	3,400	6,068
Wind	5,533	900	6,433
Hydroelectric	9,348	0	9,348
Nuclear	10,248	1,000	11,248
Total MW	**39,697**	**8,185**	**47,882**

Figure 6 | Moratorium Scenario – Energy in 2035



	Energy from Today's Capacity Remaining in 2035	Energy from New Capacity Online by 2035	Energy from Total Capacity in 2035
Storage	0	0	0
Imports	0	0	0
Demand Response	0	0	0
Natural Gas	13	0	13
Bioenergy	1	0	1
Solar	3	6	10
Wind	16	4	20
Hydroelectric	40	0	40
Nuclear	80	3	83
Total TWh	**153**	**13**	**166**

By 2035, about 5,300 MW of new solar, wind and nuclear capacity has been added. In the capacity expansion tool, new solar was first added in 2029 and then consistently throughout the study period to support summer peak demand. Wind came online in 2030, and SMRs in 2031, to meet energy requirements. About 3,000 MW of demand response was also added to the fleet.

New large hydroelectric and nuclear facilities were not selected due to lead times that extended beyond the horizon of this scenario. As firm imports from Québec would require resource development in that province,[6] they proved to be costly and were also not selected. Finally, with 2,500 MW of battery energy-storage systems included in the base supply mix, the value of additional storage diminished, hindering its selection.

As shown in Figure 6, nuclear, hydroelectric and other renewables continue to provide baseload energy, while storage and demand response are used as peaking resources with minimal output. Of the 8,000 MW of natural gas remaining by 2035, about 5,000 MW was selected for energy adequacy. The 3,000 MW balance was determined to be needed for reliability services, including flexibility – i.e., the ability to provide energy quickly to respond to unexpected changes on the system – and emergency back-up. Energy produced from this amount is expected to be limited, along with its impact on emissions.

By 2035, total capacity reaches about 47,900 MW, compared with about 38,000 MW today. (For effective capacity data see Appendix A, Tab 10 and 11.)

This mix was assessed and found to be capacity and energy adequate.

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[6] Hydro-Québec's recent strategic plan notes that "After several years of record energy sales across all our markets, tightened balances will prompt us to focus on maximizing the value derived from our clean energy." Québec's submission for NERC's Long-Term Reliability Assessment identifies the need to import/build more generation beginning in the late 2020s.

Transmission

Planning for a future that will require extensive amounts of new generation and the transmission to deliver it involves the careful consideration of many factors, including the cost and timing of development. For example, transmissions assessments indicated that in Toronto and York Region, existing gas will be needed in the Moratorium scenario because the new and/or expanded transmission infrastructure to replace it cannot be completed by 2035.

Overall, the new generation in the Moratorium scenario would require additional bulk transmission system infrastructure in the City of Toronto, York Region, east of the Greater Toronto Area, west of Barrie (Essa) and in both northwestern and northeastern Ontario. The IESO will ensure that future bulk and regional planning activities in these areas further assess the identified needs and reinforcement options and make recommendations for next steps, including development work. In particular, upcoming regional planning activities for both Toronto and York Region will need to examine options for the eventual replacement of the local reliability benefits provided by existing gas.

TABLE 3: TRANSMISSION FACILITIES NEEDED

Facility Needed	# of Facilities/Kms of Line	Location
New autotransformers	2	Essa, Toronto (Leaside)
New static volt-ampere reactive compensators	4-5	Northwest and Northeast
Refurbished 230 kV (kilovolt) lines	55 km	East (GTA East)
New 230 kV lines	5-20 km	Essa/Toronto (York Region)
New 500 kV lines	550 km	Northeast (Pinard to Hanmer)

This build-out is estimated to have a capital cost of up to $2.1 billion by 2035, over and above what is currently planned or underway. (Further details on the scope and drivers of each reinforcement are included in Appendix B, section 2.)

These findings relied on the implementation of existing transmission plans that are currently in various stages of development. This would allow the projected additional generation in the northeast and northwest to contribute to meeting provincial needs and to ensuring that sufficient supply is available in various areas across the province under the Moratorium scenario. Since these plans are already committed to meet existing needs, they form part of the 2021 APO base case.

Moratorium: Conclusion and Outcomes

The conclusion from this assessment is that a moratorium on the acquisition of new gas can be feasible after current resource procurements, but that it requires action: building on the CDM momentum; acquiring new, non-emitting resources to meet new demand and replace retiring resources; and developing the needed transmission. It also requires focused research and analysis to develop a mix of resources that can reliably replace the operability services provided by existing natural gas plants as they retire.

While Ontario's gas fleet will increase to meet mid-decade needs, the Moratorium identified the potential opportunity to reduce the overall amount of natural gas in the system from up to approximately 12,000 MW in 2027 to 8,000 MW in 2035. Of this amount, about 5,000 MW would be needed for capacity and energy, representing a 60 per cent reduction from 2027 levels. As noted above, the remaining 3,000 MW would be needed on standby for operability reasons, as the important characteristics of gas must remain available to Ontario's power system and no like-for-like replacement is yet available. Energy contributions from this amount, however, are expected to be marginal in this scenario.

In terms of emissions, the change in the resource mix and energy contributions results in an eight mega-tonne (Mt) per year decrease in forecasted CO_2e emissions in 2035, a nearly 60 per cent reduction from the APO 2021 forecasts.

The revenue requirement for this new infrastructure, combined with costs for incremental CDM programs[7] and changes to system operation, would result in a $1.9 billion net increase in annual total system costs by 2035, approximately an eight per cent increase over today's costs. This will undoubtedly lead to increased electricity costs for consumers. However, some studies[8] suggest that by 2050 these increases could be offset by savings from more efficient equipment like heat pumps and electric vehicles, as well as reductions in fossil fuel costs for transportation and heating.

With an eight Mt CO_2e decrease in emissions by 2035, the implied cost of carbon (the net increase in annual total system costs divided by emissions saved) would be $240/t$CO_2e$. (For further information on system costs, see Appendix A, Tab 8.)

[7] CDM is considered through decreased demand and associated program costs.

[8] See Electric Federalism: Policy for Aligning Canadian Electricity Systems with Net Zero, The Canadian Climate Institute, May 2022, p. 47, and "Electricity Affordability and Equity in Canada's Energy Transition, Dolter, Brett and Winter, Jennifer, the Canadian Climate Institute, August 2022.

Assessing a Pathway to a Decarbonized Future

The Pathways scenario looks at the time frame for decarbonizing Ontario's electricity system in the context of high electricity demand based on substantial electrification in other sectors.

Using the same supply base case as the Moratorium scenario, Pathways focused on 2050, assuming non-emitting resources would be available for 25 years for solar and 30 years for biomass and wind from their commissioning dates. Hydroelectric facilities were assumed to be available for the duration of the study time frame. In this scenario, up to the year 2035, gas plants were allowed to operate until they reached 25 years of age. After 2035, they were retired at the end of their contract, but kept available for reliability. This approach to the life of gas plants was informed by the draft framework for the Clean Electricity Regulation released in 2022.

Adequacy assessments were performed only for 2050, and as a result the scenario only shows capacity and energy results for that year. An operability screen was not performed, but further work will be undertaken.

Demand Forecast

The Pathways scenario, which looks out to 2050, assumes high levels of electrification in the economy. The scenario was created based on theoretical, aggressive, policy-driven electrification in three major sectors: transportation, building heat and industrial process. To develop this scenario, we did not undertake a cost-optimization exercise comparing different decarbonization options on the demand-side. The upcoming work performed by Ontario's Cost-Effective Energy Pathways Study, commissioned by the Ministry of Energy, will provide more insight on the possible evolution of demand in Ontario.

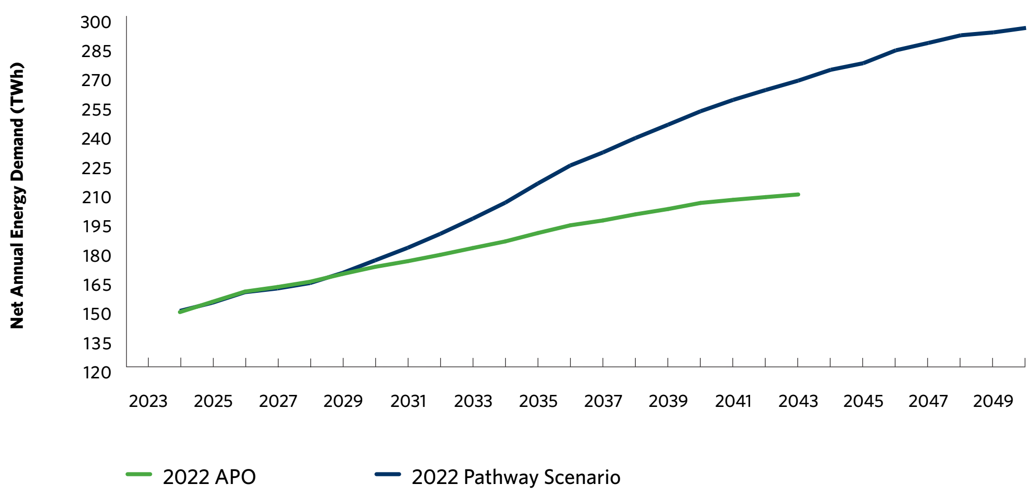
Major scenario assumptions include:

- **Buildings:** A nine-year transition from predominantly fossil-fuelled space and water heating to electric heat pumps, by 2030 for new residential and commercial buildings in Toronto, and by 2035 for the rest of the province. Technological improvement in cold-weather heat pump technology was assumed.
- **Transportation:** Electrification of passenger vehicles aligned with federal regulations; incremental electrification of medium and heavy-duty vehicles, including municipal transit buses, rail transit, and other mobility; and freight vehicles assumed to be fuel cell powered with hydrogen fuel.
- **Industry:** Broad substitution of natural gas fuel to electricity, roughly 20 per cent of current levels by 2050. If the low-carbon hydrogen is manufactured in Ontario, this new industry will represent a significant new load that is not currently included.
- **Conservation:** Assumes savings consistent with the maximum achievable potential from the 2019 IESO Conservation Achievable Potential study.

The demand scenario is based on an assumption of normal weather patterns and does not consider extreme weather events or the projected increase in overall temperature. These changes could have a significant impact on future demand, but are beyond the scope of this project.

As a result of the assumed electrification, the scenario has an average annual growth rate for 2023-2050 of 2.7 per cent for energy reaching an annual energy consumption of approximately 300 TWh by 2050, as shown in Figure 7.

Figure 7 | Energy Demand



Capacity increases by 1.5 per cent per year for summer (Figure 8) and 3.8 per cent for winter, resulting in a winter peak of approximately 60 GW by 2050 (Figure 9).

Figure 8 | Annual Summer Peak Demand

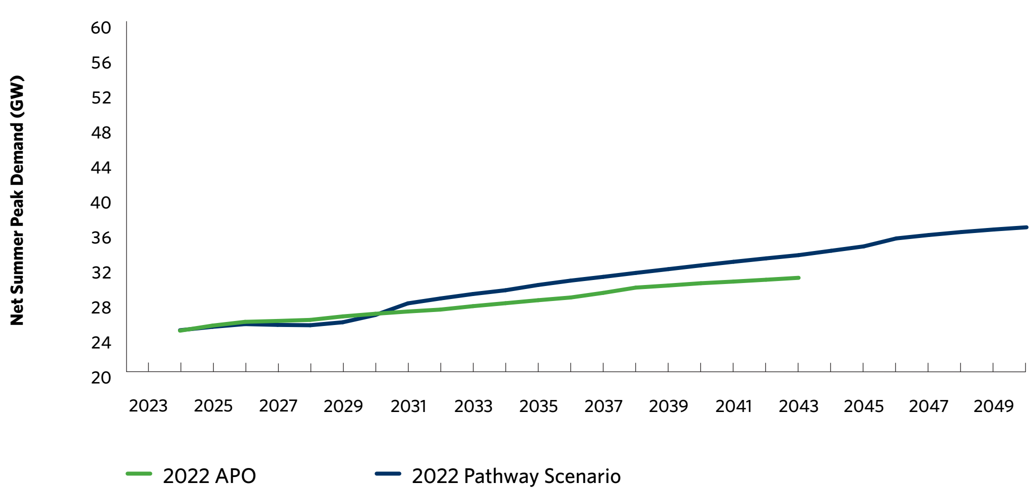
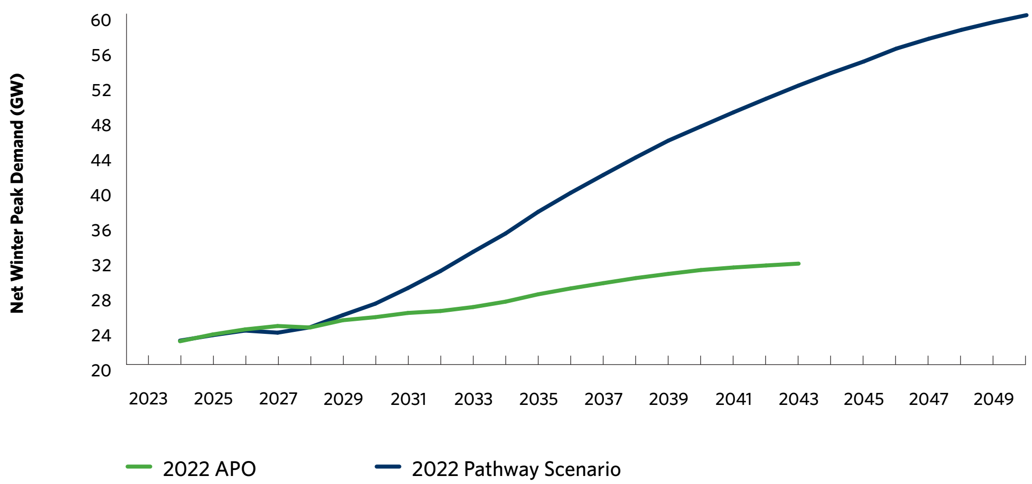


Figure 9 | Annual Winter Peak Demand



The system becomes winter peaking by 2030, largely as result of increased electrification of transportation – i.e., evening or overnight charging – and of heating requirements in buildings. This electrification also changes the shape of system demand during winter, resulting in spring and fall peaks that are higher than summer peaks.

The new profile has up to three ramps per day of 6,000-10,000 MW (see Figure 11), compared with ramps of 2,000-5,000 MW today, attributed to the forecasted new overnight coincident demand from the charging of electric vehicles after business hours and the adoption of electrically powered space heating in the winter season. Managing these ramping requirements would represent a significant operability challenge.

There would likely be an opportunity to manage winter demand through thermal storage and demand response, but there is still considerable uncertainty around the impact on daily demand of future heat pump and electric vehicle requirements. Summer demand profiles do not show significant changes (see Figure 10).

Figure 10 | Summer Daily Load Shape Hourly Profile

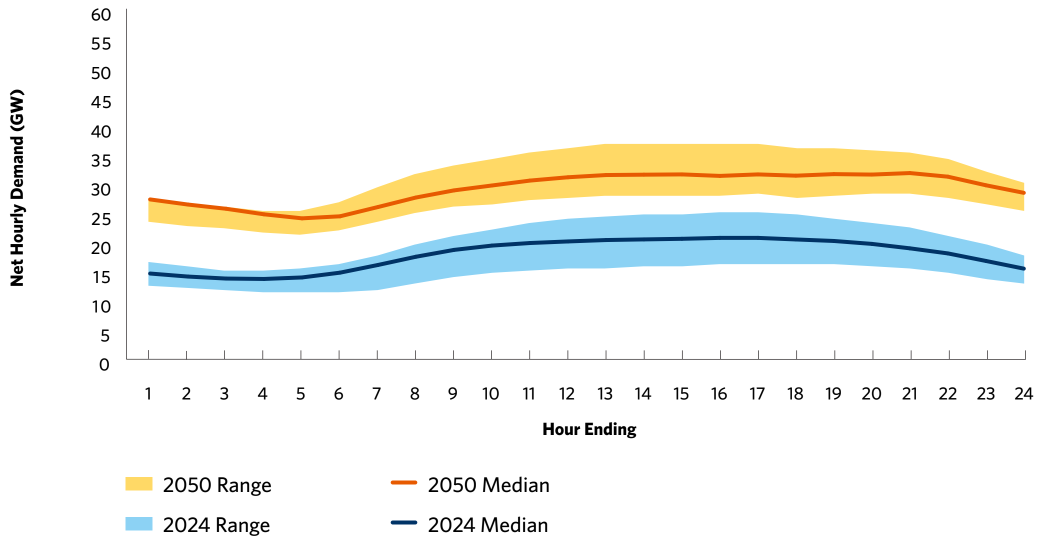
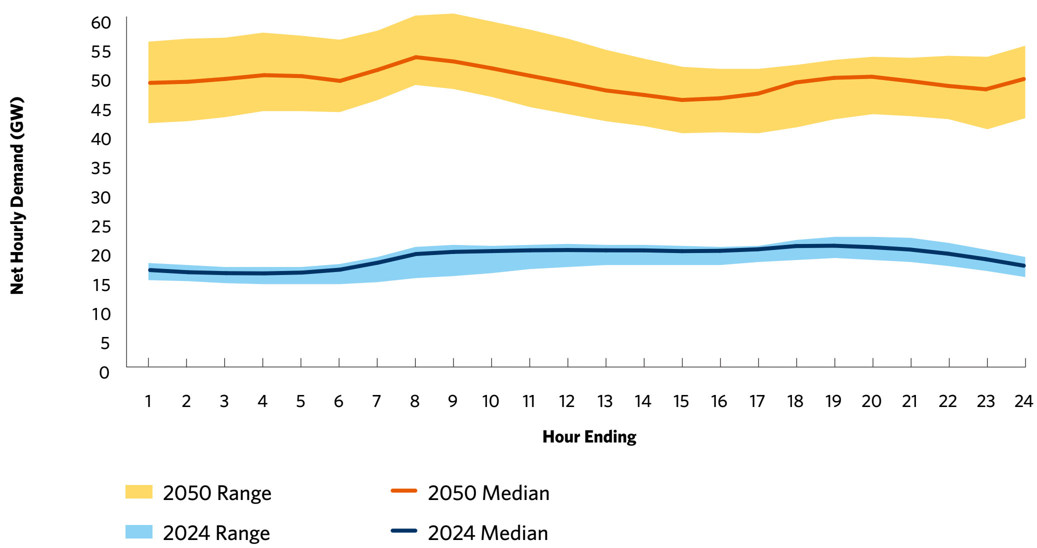


Figure 11 | Winter Daily Load Shape Hourly Profile



As with the Moratorium scenario, this forecast reflects a ramping up of CDM savings, reaching 4,650 MW of demand reduction in 2050[9] at a cost of $11.5 billion over the 2023-2050 period.

[9] These amounts are in line with the maximum potential scenario of the IESO's 2019 Conservation Achievable Potential Study.

Resource Build-out

By 2050, about 20,000 MW of today's supply is still in operation, made up primarily of large nuclear reactors and hydroelectric. Most existing renewable generation is assumed to have reached its end of life, while natural gas is phased out consistent with the zero-emissions goal.

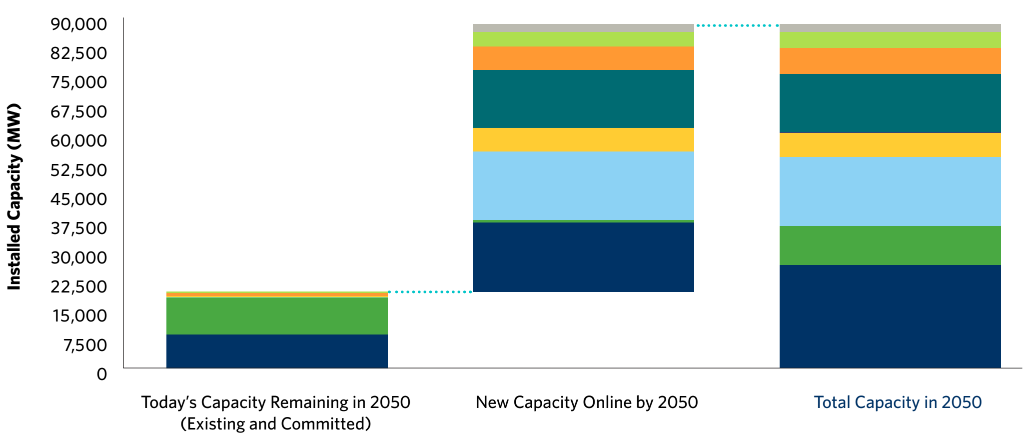
In order to reliably meet the new winter peak demand of 60,000 MW, an additional 69,000 MW of installed capacity is added, in addition to nearly 5,000 MW of CDM that is already included in the demand forecast (see Figure 12).

This scenario includes an additional 17,800 MW of nuclear supply. By 2050, as most of Ontario's existing wind facilities will have reached their end of life, this scenario also includes an additional 17,600 MW of wind and 650 MW of new hydroelectric.

Solar resources provide value during summer peaks in the early years of the scenario. As the system transitions from summer to winter peaks, the value of these resources diminishes and incremental capacity levels off at 6,000 MW in 2036. In addition, as under the Moratorium scenario, the existing 2,500 MW of batteries limited the value of further short-term storage through to 2035. An additional 2,000 MW of long-duration storage is added in the late 2030s to meet adequacy needs.

Assuming its availability in 2036, the analysis suggests that hydrogen becomes a cost-effective[10] resource for reducing peak demand.

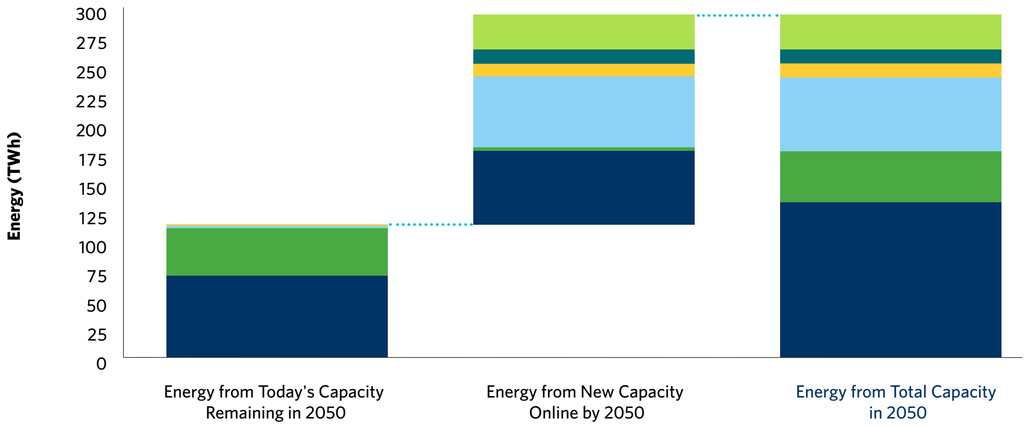
Figure 12 | Pathway Scenario – Installed Capacity in 2050



	Today's Capacity Remaining in 2050 (Existing and Committed)	New Capacity Online by 2050	Total Capacity in 2050
Storage	0	2,000	2,000
Imports	331	3,800	4,131
Demand Response	808	5,936	6,744
Hydrogen	0	15,000	15,000
Bioenergy	41	0	41
Solar	259	6,000	6,259
Wind	160	17,600	17,760
Hydroelectric	9,348	657	10,005
Nuclear	8,653	17,800	26,453
Total MW	**19,600**	**68,793**	**88,393**

[10] Although estimates are based on the most reliable information available at the time of writing, considerable uncertainty remains around cost assumptions for various fuels over the study time period.

Figure 13 | Pathway Scenario – Energy in 2050



	Energy from Today's Capacity Remaining in 2050	Energy from New Capacity Online by 2050	Energy from Total Capacity in 2050
Storage	0	0	0
Imports	0	30	30
Demand Response	0	0	0
Hydrogen	0	12	12
Bioenergy	0	0	0
Solar	1	11	12
Wind	2	62	63
Hydroelectric	41	3	44
Nuclear	70	63	133
Total TWh	**113**	**181**	**294**

Using Ontario's existing interties with Hydro-Québec, as well as incremental new infrastructure in both Ontario and Québec,[11] this scenario includes 4,000 MW of imports. Given Hydro-Québec's current winter capacity constraints, which are outlined above, we assumed that the firm imports would be from new hydroelectric and new wind facilities built in Québec.

By 2050, the total installed capacity reaches about 88,400 MW. In contrast, current installed capacity is about 40,000 MW.

This mix was found to be capacity and energy adequate.

Operability and the future electricity grid

As discussed throughout this report, ensuring reliability is of paramount importance. For a system to be reliable, it must have the flexibility to respond to sudden changes as well as extreme conditions. Future supply mixes will not have some of the traditional resources that currently provide these services, and ensuring reliability without them contains many unknowns. It will require detailed planning studies that incorporate novel approaches, tools and a thorough understanding of the location and technological features of individual resources as they are integrated into the electricity grid. As a result, the IESO has not performed an operability assessment on this scenario. The IESO will work with peers and industry experts over the coming years to address this challenge.

[11] Incremental new infrastructure would include a new intertie between the two provinces and additional reinforcements in Ontario to deliver the capacity to the load centre in the GTA. It would also include necessary reinforcements on the Québec side.

Transmission

The transmission requirements for the Pathways scenario are extensive. In order to achieve a starting point for a system that is capable of incorporating the resources identified and reliably supplying the forecast demand, a significant build-out of Ontario's existing 500 kV network would be required, focusing on paralleling the existing network where possible. Beyond reviewing the impact of different levels of reinforcement to the 500 kV network, the need for an additional 230 kV of bulk reinforcements was also identified to enable the supply mix. (Full details are available in Appendix B, section 2.)

Meeting Forecasted Demand

The challenge of connecting the forecasted demand can be illustrated by considering some high-level assumptions around how many new load supply stations (i.e., transformer stations supplying distribution customers) would be required throughout the province:

- Taking into account existing load supply stations, and assuming that a new station would supply approximately 250 MW of winter load, it would require anywhere from 150 to more than 280 new stations to meet forecasted demand, depending on whether if those stations are fully utilized.
- Costs range between $5 billion and $10 billion based on recent figures for a standard load supply station in a non-urban environment, assuming no work is required on the upstream transmission system and not accounting for downstream distribution costs.
- This would mean that between five and 10 new stations a year, on average, would be needed to meet forecast winter demand in 2050, with a yearly pace potentially outstripping the number of new stations that have been developed across the province in the last decade.

Overall, the cost of building out the bulk 500 kV and 230 kV system to meet the Pathways scenario is estimated to be between $20 billion and $50 billion. This estimate includes new 500 kV and 230 kV network lines and terminations, and new 500/230 kV and 230/115 kV auto-transformation. If 500 kV reinforcement through northwestern Ontario to Manitoba were also needed due to load growth or constraints on resource siting, this could result in an additional $7 billion to $16 billion in costs. The costs for 500 kV lines and terminations are directly informed by the 500 kV reinforcements modelled. The range of cost for 230 kV lines, terminations and for all auto-transformation was informed both by the reinforcements modelled and the unit costs per MW of load growth, assuming typical equipment capabilities.

Many of the needed investments will be challenging to implement given their location within major load centres and populations, which makes land more challenging to acquire, permitting more contested and construction more expensive if undergrounding is necessary. Aside from the bulk reinforcements needed to support growth in the load centres, the Pathways scenario also necessitates major investments in the local distribution system, including step down stations required between the transmission and distribution network, and distribution infrastructure for final connection to the customer. The cost and siting challenge for the required stations and distribution infrastructure will also be substantial.

Pathways: Conclusion and Outcomes

This scenario illustrates the magnitude of the effort required for Ontario to decarbonize its electricity system while responding to economic development and electrification. Focusing on 2050 to align with international targets, this study highlights the goals we are attempting to achieve. It demonstrates an immense build-out of the province's transmission, distribution systems and resources that could more than double Ontario's installed capacity, and that would need every known or potential resource available today. It also requires replacing the necessary services provided by gas, which no resource alone today can do.

We can garner many insights from this scenario, but it is also important to acknowledge its limits. This resource mix was assessed for energy and capacity adequacy in 2050; an operability assessment was not performed. In addition, we did not perform adequacy assessments for the years before 2050. Further planning work is necessary to understand how to manage the transition in a reliable way from now to 2050.

This scenario relies heavily on low-carbon fuels for intermediate, peaking and flexibility needs. Currently there is no like-for-like replacement for the operating characteristics of natural gas. Low-carbon fuels might be able to fill this gap and would be a valuable addition to the supply mix, but they do not yet exist at scale and there are many barriers to commercialization. (See Appendix A, Tab 9.) If low-carbon fuels do not materialize, replacing natural gas will be an even more complex task, requiring more research and analysis into understanding how generation, demand, transmission and storage can be combined to replace gas. It may be possible to overcome all of these barriers, but it will require concerted effort by government and innovators.

In terms of both transmission and supply, the Pathways scenario would need $375 billion to $425 billion in new infrastructure investment, and result in an annual total system cost of approximately $60 billion by 2050. Alternatively, annual system costs can be considered per unit of demand at $200 to $215/MWh, an increase of between 20 per cent and 30 per cent from current unit rates.

Regarding consumer bills, it is difficult to determine a potential rate impact given the changing nature of energy consumption. However, an increased reliance on electricity will significantly increase the volume of consumption on bills compared to today's patterns. (Further information on system costs is available in Appendix A, Tab 8.) However, as noted above, some studies suggest that actual impact on total energy costs could be modest due to offsets and increased efficiency.[12]

[12] Canadian Climate Institute op. cit., p. 26

Natural Gas as a Transitional Resource to Ensure Operability

Natural gas generation currently plays a vital role in supporting grid reliability: it can generally provide continuous energy throughout the year, under all weather conditions; it can be ramped up or down within minutes to follow sudden or unexpected changes in demand or in the availability of other generators; and it provides reliability services that help stabilize voltages and frequencies on the transmission grid.

These important characteristics must remain available to Ontario's power system, which means that natural gas facilities are needed past 2035, or until reliable replacements have been identified, put into service and demonstrated their capability.

Developing a strategy to replace natural gas facilities requires a number of thorough, detailed assessments. As learned during Ontario's coal phase-out initiative, shutting down large facilities while maintaining reliability can take many years to achieve. Some of the learnings from Ontario's previous experiences include the following:

- Replacement resources should be procured, built, commissioned and operated at a satisfactory level of performance prior to the shutdown of facilities. Careful scheduling and demonstration of operation are critically important to ensuring that reliability can be maintained during transition years.
- Replacement resources are unlikely to have the same attributes as natural gas facilities. Low-carbon fuels such as renewable natural gas, for example, may be suitable replacements, but significant work must be done to ensure that they have both the right technical characteristics and that they are market ready in sufficient quantities by 2035. In the end it may be necessary to procure additional resources to ensure that all reliability attributes are replaced.
- Shutting down larger facilities can impact the transmission system. Studies should be conducted as each facility shuts down to understand the broader effects on the transmission system and to develop adequate infrastructure to maintain the security of the grid.

Coordinating outages is critical during the years where new replacement facilities and supporting infrastructure are under construction and commissioning. A staged approach allows facilities to shut down while broader impacts to the grid are managed effectively.

Replacing these facilities will be complex and will require detailed assessments and studies that will be a priority for the IESO going forward. In addition, it may require the development of new reliability standards.

Implementation Dependencies and Risks

While the energy transition will bring growth opportunities, the results of both scenarios demonstrate the complexities of achieving it. The electricity system will be relied upon to do more than ever while learning how to build and manage resources at a scale never before attempted.

Today, there is considerable activity underway in planning for Ontario's future reliability. The IESO's current resource procurements, along with CDM program development and efforts to enable emerging non-emitting resources, are all moving the province steadily forward toward meeting its coming needs.

Bridging the work of today with the needs of a decarbonized world will be challenging and complex, but Ontario has the experience to build on.

- After becoming the first jurisdiction in North America to completely phase out coal-fired generation in 2014, our electrical grid is now more than 90 per cent emissions-free – one of the cleanest electricity systems on the continent. On average, the system accounts for just under three per cent of the province's emissions;
- We have a mature sector, with established, knowledgeable electricity market participants, an experienced system operator and a respected energy regulator;
- We are part of the largest, most reliable grid in the world, and adhere to the requirements of North American standards authorities (NERC/NPCC) to ensure the reliability and security of Ontario's system;
- We have extensive experience with demand-side management programs; and
- We have a skilled, well-trained workforce and well-developed infrastructure to attract economic development.

That said, there are many dependencies and risks involved in making the transition to a decarbonized electricity system; these were brought to the IESO's attention during the stakeholder and community engagement process that has informed this body of work. Some of the more significant dependencies and risks are outlined below.

Policy certainty is a must: Provincial and federal policy in Canada must set mandatory goals for GHG emissions reductions, which, in turn, govern the direction of industry, business and consumer behaviour. Policy certainty – both in the near and long term – is vital to enabling investment in infrastructure, CDM, next-generation technology and decarbonization. Uncertainty around the future cost of carbon and emissions targets contributes to a challenging environment for investors and others interested in contributing to meeting reliability needs. Stakeholders emphasized that policy certainty is a prerequisite for decarbonization at scale.

Governance and oversight need to evolve with the challenge: The pace of electrification will depend on millions of individual choices by households and businesses regarding transportation, heating and cooling solutions and appliances. Those choices will be influenced by factors such as the relative cost of various options, the presence of supporting infrastructure and even geopolitical developments. This makes electricity system planning and investment challenging and may require an evolution in how the sector is governed to ensure an orderly energy transition.

Public support for decision-making is vital: Public support will be necessary to enable the transition. A recent report, Net Zero: An International Review of Energy Delivery System Policy and Regulation for Canadian Energy Decision Makers, concludes that "Durable public support for energy system transformation will need to rest on open, inclusive, transparent policy, planning and approval processes, engaging communities and citizens from beginning to end" (p. 5). This will involve acknowledging the costs and risks of the transition, as well as addressing how we pay for it.

Managing costs is a precondition to success: Stakeholders and experts are concerned about the effect of this energy transition on affordability, including the impact on industrial competitiveness and of rising costs on people with low incomes. This is a significant issue and highlights the need to adopt a cost optimized pathway. Recent analysis published by the Canadian Climate Institute shows that if the pathway is cost optimized, while electricity rates would increase, overall energy costs would decline as equipment becomes more efficient and the share of spending on natural gas and gasoline decreases.[13]

A partnership role for Indigenous communities is a prerequisite: Simply consulting Indigenous communities on planned system developments has never been a sufficient approach to electricity system planning: these communities expect to be full partners in the transition to a decarbonized future. Indeed, Indigenous communities, governments and organizations across Canada have been actively developing renewable-energy and transmission projects over the past two decades. Today, First Nations, Métis and Inuit entities are partners in, or beneficiaries of, almost 20 per cent of Canada's electricity-generating infrastructure, most of which is producing renewable energy. These communities are also seeking efficiency improvements in their buildings and want to see job creation in their communities. The electricity sector has already created a solid foundation of engagement with many Indigenous communities and is well positioned to build on this base.

Permitting and approvals must be streamlined: In Canada, it can take many years to build new energy infrastructure; the IESO's experience is that it can take four to five years for new wind and solar generation, 10 years for transmission networks and even longer for large, capital-intensive infrastructure. Stakeholders, communities, experts and infrastructure developers have made it clear that processes need to be enhanced and streamlined if Canada wants to build energy infrastructure at the scale needed to reliably decarbonize. It is imperative for all levels of government to review their processes, including the Impact Assessment Act, the Environmental Assessment Act, and siting approval and permitting processes.

[13] Canadian Climate Institute op. cit., p. 26

Siting grid-scale energy infrastructure will require the support of communities: All new infrastructure has to be placed somewhere and taking community concerns, needs and plans into consideration is critical to the expansion of the system. An estimate of land use required for incremental resources in the Pathways study would be almost 14 times the size of Toronto (see Appendix B, section 6). Some municipal representatives want to participate in the energy transition, but have noted that it is critical that they have some control over the type of infrastructure that will be built in their community. Thus, an important part of the system's planning process is looking at siting from a local perspective, as well as helping communities understand the challenges and opportunities of siting new infrastructure. The IESO is already working with government to preserve transmission corridors to enable future growth.

The impacts of decarbonization on the distribution system need to be considered: Decarbonizing Ontario will necessitate a considerable increase in the demand for electricity, which, in turn, will have a significant impact on the distribution system, local distribution companies and on the cost to the government and citizens. Toronto Hydro, for example, recently estimated that it will cost the distributor $10 billion by 2050 to build a grid that's capable of supporting the city's net-zero strategy. Coordination between the bulk and distribution systems is needed to ensure that this transition is reliable and efficient, and to maximize the value of DERs.

Access to capital, resources and labour may be challenging: The path to decarbonization is not only being considered in Ontario; jurisdictions around the world are planning or actively working on decarbonizing their energy systems over the next 25 years. As a result, competition for scarce resources is already becoming an issue, while volatile geopolitical realities and the COVID-19 pandemic continue to weaken supply chains. Many stakeholders have told us that finding skilled labour, capital and sources of supply are serious challenges to achieving decarbonization goals, and one study (see Appendix B, section 6) estimates that the 14,000-strong labour force currently working on electricity infrastructure projects in Ontario could need to increase six-fold for decades. The electricity sector and governments need to work together to develop a strategy to collectively face these uncertainties and sourcing challenges.

Innovation is important, but uncertain: While many of the technologies needed to decarbonize are already known and commercialized, many others, including low-carbon fuels and SMRs, are still in development. It will be important for Ontario and Canada to continue to invest in these, and other, innovations. As the system planner, however, we must consider scenarios in which these technologies become available, as well as scenarios in which they do not.

Conclusion

This report is the IESO's response to the Minister of Energy's request to evaluate a moratorium on the procurement of new natural gas generating stations in Ontario and to develop an achievable pathway to decarbonization in the electricity system.

The Moratorium and Pathways scenarios are not integrated power system plans, but analyses that identify potential opportunities and challenges to consider as Ontario electricity demand and its resource mix evolves. As well, although this scenario analysis is just the beginning of a discussion about how to decarbonize our system while maintaining reliability and managing cost, it provides a solid understanding of the scale of the work and clearly demonstrates the need to collaborate to address risks and dependencies.

This study found that a moratorium on new natural gas is possible after the province's current round of electricity resource procurements is complete – as long as development begins now. Informed by robust planning, Ontario must begin to acquire new non-emitting resources to meet the province's growing needs and must invest in pre-development work to better manage future uncertainty.

In response to the Minister's second question, we were able to develop an energy-adequate, decarbonized supply mix for 2050. Within the Pathways scenario, Ontario's system became zero-carbon in 2045 when the last natural gas plant retired after 25 years of operation, but further assessment is needed to determine the feasibility of this target as well as a cost-effective way to get to 2050.

In addition, the Pathways scenario points to a step change in how we grow and manage our electricity system. In order to meet a projected 60,000 MW of customer demand, Ontario will need all of the resources available to it to simultaneously expand and decarbonize. While many options are already available and understood (wind, solar, hydroelectric and large nuclear), others options such as SMRs and low-carbon fuels will require support, and their availability is not guaranteed.

Another key area of uncertainty identified in the development of this report relates to the proposed federal CER. It will be important that these regulations are informed by system planners and operators. For example, our assessment of the Moratorium scenario has led us to conclude that we will require 8,000 MW of natural gas on the system in 2035, particularly in the GTA, to ensure reliability. We will continue to work with the federal government to share our insights and perspective.

In this report, we have identified decarbonized scenarios for Ontario. Scenarios, however, are not enough. If Ontario wishes to make decarbonization a reality, a number of risks and dependencies must be addressed, including policy certainty, governance framework and regulatory barriers, siting and permitting, Indigenous and municipal partnerships and the management of costs. More broadly, this report underscores the need to galvanize collaboration with a wide range of stakeholders and communities as we explore ways to develop non-emitting resources to meet Ontario's energy needs.

For its part, the IESO will incorporate the learnings from this report into our core work, more explicitly integrating the risks of climate change and the ongoing energy transition into our planning and procurements. This includes ensuring that regional planning processes for Toronto and York Region address the unique challenges for local reliability of phasing out natural gas. We will also study options to replace the operability services currently provided by natural gas, and will continue to use our procurement framework to re-acquire existing resources.

Recognizing that Ontario's demand is growing, that existing resources are retiring, and that government may direct system decarbonization, the IESO has identified "no regrets" actions that are necessary to ensure that the electricity sector is ready to manage future uncertainty and risk. These actions are intended to keep options open while maintaining the flexibility to take advantage of opportunities as they emerge.

1. Advance Acquisition of Non-Emitting Resources to Meet Load Growth

The IESO is forecasting increased supply needs out to the end of the decade, with the possibility that electrification and economic development outpace projections. Ontario should continue to move swiftly to acquire new non-emitting resources and incentivize energy efficiency to meet emerging needs. Using its competitive and technology-diverse approach to resource acquisition, the Minister is requested to advance the efforts by directing the IESO to:

- Acquire new non-emitting resources this decade through future procurements. This includes continuing to issue a regular schedule of procurements into the next decade to create investor certainty.
- While current Save on Energy programs are on track to achieve all feasible energy efficiency within the current framework, expanded targets post-2024 need to be established. Offerings should be expanded to include efficient electrification and move away from time-bound CDM Frameworks to an enduring model that adapt funding and targets to Ontario's achievable potential. Discussions regarding appropriate targets and models should begin now to better leverage CDM as a resource to respond to evolving system, market, and customer needs.

2. Invest in Future Infrastructure and Innovation

There is an urgent need to begin investing in early development work to ensure that the grid is ready to support transformation into the next decade. A relatively small investment today ensures that the projects and technologies can deploy more readily to meet decarbonization targets. Recommendations to prepare for future infrastructure and innovation include the following:

- Sector partners should begin planning and siting work to identify potential new projects, including hydroelectric and nuclear. To enable this work, the Ministry should work with the Ontario Energy Board (OEB) and the IESO to develop a process to recover pre-development costs for OEB-regulated and IESO-contracted projects respectively, as applicable.
- The IESO should work with government and system transmitters to identify new, and protect existing, corridors of land as well as rights of way that will likely be needed for future transmission lines. The IESO should also leverage existing planning processes to identify and recommend development work for priority transmission investments to support decarbonization.
- There should be an increased focus on the work identified in Ontario's Low-Carbon Hydrogen Strategy, including recognizing if and how low-carbon fuels can contribute to the decarbonization of the electricity grid. Other investments in innovation and new technologies to meet future needs will also be critical. This includes continuing to expand efforts associated with the IESO's Innovation Framework as well as the Grid Innovation Fund.
- The IESO should pursue a deeper understanding of the role of long-duration storage such as pumped water and compressed air storage, contributing to reliability needs in the 2030s. This work could lead to procurements for long-duration storage that would allow the province to reduce its reliance on natural gas earlier.

3. Galvanize Collaboration

As there is no one solution to addressing the challenges and opportunities ahead, it is important to engage, understand and build support for a collective approach to how Ontario moves its electricity system toward decarbonization. This will require both sector stakeholders and communities to take an active role in implementing solutions. To achieve this, the IESO recommends that the Minister:

- Consult on the findings of the Pathways to Decarbonization report to ensure there is a broad understanding of the report's conclusions and to build acceptance for Ontario's energy policy moving forward;
- Continue to build partnerships with the federal and municipal governments to ensure a shared alignment of energy policy and approaches to managing the cost of Ontario's energy transition; and
- Continue to build partnerships with neighbouring jurisdictions, both in Canada and in the United States, that are undergoing similar energy transitions to share learnings and collaborate on potential solutions.

4. Break Down Regulatory Barriers

The scale of the energy transition is far reaching and will require new regulatory approaches to govern how Ontario makes decisions and develops and pays for its energy infrastructure. The IESO recommends that the Minister:

- Continue the work of the Electrification and Energy Transition Panel and establish a new long term energy planning process that is designed to address the energy transition; and
- Work with all levels of government and with regulators to ensure that approaches to regulating the development of new large infrastructure projects and expanding the use of CDM, DERs, and other innovative technologies are appropriate given the scale and pace of the challenge ahead.

5. Track Progress and Update Plans in an Open and Transparent Process

This study is a single scenario based on the information available to the IESO today. It is imperative that Ontario continue to update, track progress, and refine its planning in support of the energy transition. To do this, the IESO recommends that the Minister:

- Direct the IESO to establish a new and enduring process to track progress and plan for Ontario's energy transition. The planning should be incorporated into regular planning products such as the IESO's APO. The first iteration should account for the results of the actions identified above.

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